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## THESIS

THE OPTIMAL FORCE MIX AND  
ALLOCATION OF FIRES FOR  
THE FUTURE FIELD ARTILLERY

by

John Mann Page

September, 1991

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for the Future Field Artillery

by

John Mann Page  
Captain, United States Army  
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Submitted in partial fulfillment  
of the requirements for the degree of

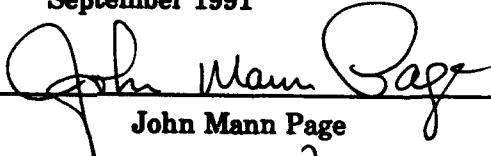
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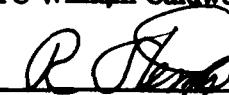
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## ABSTRACT

The new Army warfighting doctrine, AirLand Operations, is designed for the army of the 90s, a smaller army, but one which will be faced with global responsibilities. These responsibilities will range from fighting wars and regional conflicts, to conducting various peacetime operations in support of allies in the realm of Low Intensity Conflict. Our success under AirLand Operations will largely depend upon the ability of the Field Artillery to disrupt enemy C3 elements, and destroy troop formations from extended ranges early in the battle. The Artillery School (USAFAAS) is currently developing several advanced systems to accomplish this mission. The focus of this thesis is the Artillery Attack Model (AAM). The AAM is a GAMS Mixed Integer Linear Programming model developed to assist USAFAAS determine the Minimum Cost Weapon/Munition Mix and Allocation of Fires to targets in order to meet the commander's kill criteria on the future battlefield.

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The reader is cautioned that the computer program developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the program is free of computational and logic errors, it cannot be considered validated. Any application of this program without additional verification is at the risk of the user.

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## I. INTRODUCTION

### A. OUR NEW WORLD ORDER

#### 1. Era of Change

Our era has been characterized predominantly by change, which has affected every aspect of our society, including the profession of arms. The three key elements of change which have borne the greatest impact upon our National Military Strategy are: the radical changes in the international political environment, our national fiscal concerns, and the emergence of radically advanced technologies. As a result of the "New World Order" our National Military Strategy must also change.

In the past we lived in a bipolar world dominated by the United States and the Soviet Union. We principally practiced a Military Strategy of Forward Defense of Western Europe in response to the potential threat of nuclear war or High Intensity Conflict with the Warsaw Pact armies. Over the past two years we have witnessed the destruction of the Berlin Wall and the reunification of Germany, as well as the collapse of the Warsaw Pact, and the democratization of the Soviet Union. We have also witnessed the signing of the Conventional Forces Europe (CFE) Treaty and the initial withdrawal of Soviet troops from the region. With the disintegration of the Warsaw Pact and the breaking-up of the Soviet Union, the Soviets' influence has largely subsided as they turn their focus inward to resolve their own internal political and financial crises. Yet the Soviet Union will continue to be the major military force with which we may have to contend since, despite all of its internal struggles, the Soviet Union continues to modernize both its conventional and nuclear forces, as well as

expand its space based research efforts. However, in light of recent world political developments and Soviet internal problems, the US would face a major Soviet threat in Europe only after a long and visible preparation process.

The United States is also experiencing its own internal crises, specifically it is faced with a budget deficit of monumental proportions. As a result, all branches of government are faced with the difficult task of reducing the government workforce and scaling back funded social and defense programs in an effort to reduce this deficit. For the military, the impact equates to a reduction of force size and a decrease in the budget with which to equip the force.

The third element of change is the rapid emergence of advanced technologies. As the CNN images of precision-guided, long-range Tomahawk cruise missiles sailing across the morning skies of Baghdad portrayed - we can now see the battlefield with much greater resolution and immediately respond to what we see with accurate long-range missiles, rockets, and cannons.

## **2. A New Threat**

In light of these changes, we find ourselves facing a much different threat than in the past, one much more diverse; one which requires a much different National Military Strategy. We now find ourselves living in a world whose politics and economics are being influenced primarily by emerging regional powers (e.g. Japan, Germany, and Korea). As the recent Iraqi invasion of Kuwait aptly demonstrated, these regional powers may pose a serious threat to our national interests. These potential

threats are global in nature and range from the Middle East and Northeast Asia to Latin America. Additionally, they represent a broad spectrum of operational challenges.

In the future, these potential threats may prove even more dangerous due to the proliferation of advanced weaponry, including weapons of mass destruction. In addition to these more obvious potential threats, problems of famine, violence, and natural disaster will most certainly lead to conflict within developing nations. The threat of drug traffickers and terrorists is ever present and, in these days of the shrinking defense dollar, those responsible for the appropriation of government funds have simultaneously called for the military to take a larger role in combatting these unconventional threats.

### **3. A New National Military Strategy**

Our revised National Military Strategy must now largely focus on our flexibility and our ability to project varying levels of combat power to different parts of the world. Although we must still maintain some forward presence, it will be much reduced from previous levels.

In support of this strategic direction, the US Army must continue to provide well-trained, combat-ready forces capable of deploying into varying situations along the entire Operational Continuum of War, Conflict, and Peacetime Competition, on relatively short notice. War and Conflict are hostile states dominated by the use of force. Peacetime Competition is a non-hostile state in which we assist allies and promote democracy through providing military and economic assistance.[Ref. 1] Previously, our AirLand Battle doctrine focused on the Warsaw Pact threat in Central

- Europe, a mechanized Middle East threat, and the threat posed by North Korea. In today's multi-polar political/military environment the Army's warfighting doctrine must clearly refocus on the much more diverse threat which we now face.

## **B. AIRLAND OPERATIONS: OUR NEW DOCTRINE**

In light of these political, economic, and technological changes, the Army has developed a new strategy geared for the US Army of the 90s. This army will be a smaller army. However, it will be faced with global responsibilities ranging from fighting wars and regional conflicts, to conducting various peacetime operations in support of our allies in the realm of Low Intensity Conflict. The Army's revised warfighting strategy is known as the doctrine of "AirLand Operations." AirLand Operations refocuses the concepts and capabilities of AirLand Battle for an army trained and equipped to deploy anywhere in the world and handle a broad spectrum of missions once deployed.[Ref. 1] As the threat analysis indicates, we must be well trained in all three levels of operations (War, Conflict, and Peacetime Competition), equipped to deal with all three, and rapidly deployable to respond to any one (or more) which threatens our national security.

Of all the changes, technological advancements have had the greatest direct impact on the battlefield, where they have completely reshaped the conduct of our operations. In the past we have primarily operated on a structured "linear" battlefield with set unit boundaries and established terrain objectives. Every unit was tied in with its adjacent units. Revolutionary surveillance assets now allow us to accurately locate and monitor enemy forces on the battlefield, while new weapons technology gives us the potential to engage them with indirect fire at longer ranges and with increased

lethality and accuracy. As a result of these factors, operations conducted on the future battlefield will be extremely fast paced and much more lethal. With the downsized army, we will have fewer forces operating across larger areas which will result in sizeable gaps between units. Unit operations must be highly synchronized but much more independent resulting in a concept termed the "Nonlinear Battlefield."

Operations on the Nonlinear Battlefield will be characterized by frequent moves, with units remaining dispersed except when massing to fight the maneuver battle in order to maximize survivability. These operations will take place in four stages:

**1. Detection - Preparation**

During this stage, the commander determines how he wants to fight the enemy. He employs various electronic and human sensors and intelligence systems (ground, air, and space based) to locate, acquire, and target enemy units.

**2. Establishing Conditions for Decisive Operations**

During this stage, the commander uses long range Field Artillery fires and air assets against specific targets to weaken the enemy in preparation for the ground maneuver forces to move in and defeat the enemy.

**3. Decisive Operations**

This is the stage during which maneuver forces engage the enemy forces, both directly and with supporting close Field Artillery fires, in order to win the decisive battle.

**4. Reconstitution**

Following the decisive battle, maneuver forces disperse and reconstitute to perform sustainment operations.

### C. FIRE SUPPORT IN AIRLAND OPERATIONS

One of the key principles of AirLand Operations is to destroy enemy forces at long range with precision fires. The goal is to take advantage of new acquisition technology which indicates where significant enemy forces are located on the battlefield. We are then able to minimize friendly casualties by avoiding a battle of grinding attrition. Instead, we engage the enemy with maneuver forces after he has been attrited to the point where we are able to quickly and decisively overwhelm him.

Clearly, under AirLand Operations the effective Fire Support of the US Army Field Artillery is absolutely crucial. It is the means by which enemy forces are conditioned prior to and during the decisive battle [Ref. 2].

Artillery fire support currently comprises both the Operational Fires of the Army Tactical Missile System (ATACMS), and the Tactical Fires of both Multiple Launch Rocket System (MLRS) rockets and cannon weapon systems. Operational fires are conducted in support of Corps level objectives and focus on longer range targets -these are referred to as Deep/Long Range Fires. Tactical fires are conducted in support of Division and Brigade level objectives and focus on shorter range targets - these are referred to as Close/Short Range Fires. The specific mission of each type of fire support is outlined below:

#### OPERATIONAL FIRES:

- Seize/retain initiative
- Destroy enemy forces/targets
- Isolate battlefield
- Desynchronize C2
- Set decisive conditions

#### TACTICAL FIRES:

- Destroy enemy forces
- Counterfire
- Isolate battlefield
- Close support fires
- Final destruction of threat

## **D. STATEMENT OF THE PROBLEM**

### **1. Background: Legal Mix VII Study**

The US Army Field Artillery School's (USAFAS) Directorate of Combat Developments (DCD) is currently conducting a one year study titled "Legal Mix VII" to determine the optimal force mix, unit organization, and tactical employment of future fire support under the AirLand Operations concept. USAFAS is currently developing several new weapon systems and munitions in order to provide the long range fires necessary to support the force on the Nonlinear Battlefield. Among the issues Legal Mix VII is addressing is: " What is the most efficient, combat effective mix/combination and employment of these next generation weapon systems and munitions to support the Corps Deep Fires battle?"

### **2. The Next Generation Artillery Systems**

#### ***a. Army Tactical Missile System Block I***

The Army Tactical Missile System Block I (ATACMS I), is an improved conventional munition missile fired from the MLRS launcher. It can fire in excess of 100 km and is three times as accurate as its predecessor, the Lance missile. It was fielded early in order to be used in the Gulf War.

#### ***b. Army Tactical Missile System Block II***

The Army Tactical Missile System Block II (ATACMS II), will be equipped with terminally guided submunitions in order to destroy moving enemy armor. The missile dispenses its submunitions once it is in the vicinity of the targets. The submunitions then glide towards the armored vehicles until they acquire a specific target to attack.

*c. Paladin M109A6*

The Paladin M109A6 is an improved version of the current M109 155-mm self-propelled howitzer. The Paladin, referred to in this study as the Howitzer Improvement Program (HIP), is equipped with an on-board navigation and computer system and will provide improved range, survivability, reliability, availability, and maintainability.

*d. Sense and Destroy Armor Munitions*

Sense and Destroy Armor munitions (SADARM), are being developed for both the HIP and the MLRS. SADARM is primarily a counterfire munition - used to destroy enemy artillery. The SADARM projectile releases submunitions over the target area which descend by parachute. The submunitions identify targets using millimeter wave or infrared sensor technology, and explosively fire penetrators onto the enemy elements.

*e. Terminally Guided Projectile / Warhead*

The Terminally Guided Projectile (TGP) and the Terminally Guided Warhead (TGW) are autonomous, terminal-homing, fire-and-forget munitions which use a millimeter wave seeker to acquire the target. The TGP is fired from the HIP, and the TGW is fired from the MLRS.[Ref. 3]

**3. Scope and Purpose**

This thesis focuses on the employment of these systems during the Deep Fires battle in support of US Corps operations in all possible Operational Scenarios in the year 2000 and beyond. The purpose of this study is to assist USAFAS in determining the optimal force mix and allocation of fires of these future Field Artillery

systems. Given the level of damage and effectiveness required by the Corps battlefield commander and the capabilities of our new developmental Artillery systems, as well as a projected threat assessment, a GAMS Linear Programming model was developed to assist in determining how many of these new systems (delivery system and munitions), to manufacture and how to best allocate them to targets on the future battlefield in order for the commander to meet his mission effectiveness requirements.

## II. PROBLEM APPROACH

### A. APPROACH TO FORCE COMPOSITION AND ALLOCATION OF FIRES

#### 1. Optimizing Long Range Fires

Under AirLand Operations, our success clearly depends upon our accomplishing three things. First, we must effectively disrupt and destroy the enemy's Command, Control, and Communications (C3) elements. Second, we must destroy a significant portion of the enemy forces across several echelons (levels/belts of enemy formations), extending our attack well to the rear of his first echelon front-line forces. Without effective C3, and heavily attrited, the remaining enemy forces will be much less capable of mounting a coherent, coordinated attack or defense. Finally, our success depends upon our ability to deploy our maneuver forces to engage and destroy these remaining elements. If we can effectively accomplish the first two, we should be able to accomplish the third without suffering heavy losses.

This strategy therefore hinges on our ability to acquire and destroy enemy C3 assets and troop formations from extended ranges early in the battle. Advanced acquisition systems, such as the Joint Surveillance Target Attack Radar System (JSTARS), provide us with the location of these targets. We then depend upon our long range artillery systems, as well as air assets, to destroy them. For the purposes of this study we will only address the role of the long range artillery.

The new artillery systems being developed are technology intensive, and therefore much more expensive than previous systems. With a limited budget, we can only afford a limited inventory. They also take longer to manufacture than the

cannons and high explosive rounds of past conflicts. Yet we expect future conflict to be fast paced, highly lethal, and short in duration. Hence, we must plan to fight a "come as you are" war. We will not have time to gear up production in order to build up the inventories of the most needed systems. We must take a look now at the systems we are currently developing, in order to project which systems to build over the next decade and how many of them we will need in our inventory by the year 2000.

Our most tightly constrained resource is the money we need to build this future artillery inventory. Therefore, the specific objective of the study is to provide USAFAS with a tool to determine the most cost effective weapons and munitions mix with which to equip our army in the future, in order to defeat the enemy force. For the purpose of this study, defeating the enemy is specifically defined as meeting the Commander's Kill Criteria. The Measure of Effectiveness applied to the Kill Criteria is the overall percent of each type of enemy system killed over the entire battle.

Once deployed, these weapons and munitions will be arrayed against diverse types of enemy systems located all across and at all depths of the battlefield. Therefore, in order to determine the optimal force mix, we must determine the optimal weapons and munitions to use to attack each type of system in order to defeat the enemy we expect to face in the beginning of the next century.

To assist the Artillery School solve this problem, I developed the **Artillery Attack Model** Linear Programming model formulation and GAMS program [Ref. 4]. Of course, the results of the model depend upon the specific Operational Scenario which is used in the model. With the rapidly changing political environment, there are many possible enemy forces we could face in a variety of locations and climates. The

model is designed to be a personal computer portable tool, flexible enough for the artillery force development planner to use to determine the optimal weapons and munitions mix for any of the possible scenarios . Although the model is primarily intended to answer the mix (composition), and allocation question for the artillery systems currently being developed, it is also flexible enough to incorporate the existing weapon and munition inventories of the current systems. Once the composition of the necessary systems is determined, they can be budgeted, procured, pre-positioned, and manned. Then when we " come as we are " onto the next battlefield, we will truly come with what we need to meet our crucial missions under AirLand Operations.

## **2. The Deterministic Aggregated Combat Model Approach**

In the Artillery Attack model, all combat processes are treated deterministically. In addition, weapon, munition and target entities are aggregated together rather than treated individually. This provides the flexibility necessary to model large artillery elements and their opposing enemy forces without developing a large, expensive, high resolution model. Aggregation also keeps the model within the limits of reasonable execution time on a micro-computer. Long range fires are therefore modeled using average rather than individual engagements. Using Heterogeneous Aggregation, weapons, munitions, and targets are each tracked by total number of each sub-type.[Ref. 5] Specific aspects of this aggregation approach to the combat modeling portion of the study include:

*a. Operational Scenario*

The entire study is driven by the Operational Scenario we expect to face in the future. The key element of the Operational Scenario is the nature of the enemy force:

1. Who is the enemy?
2. With what systems is the enemy equipped?
3. Where are enemy elements located on the battlefield?
4. When are the enemy elements deployed there?
5. How does the enemy fight (fire and maneuver)?

Other elements of the scenario include: the geographical location and characteristics, as well as the civil/political situation. In the model, the enemy weapon systems are categorized as "Targets," and all the information inherent to the Operational Scenario is aggregated into the Target Data input by the user of the model. The user defines the different types of Targets, and inputs them by quantity, location, and battle time phase. He defines how they fight by entering general mobility and lethality data. Through this methodology, the model can be applied to any of the possible Operational Scenarios being postulated.

*b. Battlefield Representation*

The battlefield is represented by a series of Range Bands. The depth of the Range Bands, which is defined by the user, determines both the weapons/munitions that are capable of ranging the target and the distance advanced by the attacking forces during each phase of the battle. This allows the user to

represent a specific operational scenario with enemy forces properly templated across and to the full depth of the battlefield.

*c. Time Advance Mechanism*

The model uses a Fixed Time Step to incorporate the passage of time. This allows the user to depict the variable movement of attacking forces on the battlefield. The time step is called a "Phase" and its length is set by the user.

*d. Movement*

The movement of offensive forces is modeled by assigning a movement rate to each type of enemy element. All elements of a specific type advance the same number of Range Bands per Phase, depending upon the rate input by the user. To depict enemy offensive scenarios, each enemy element is assigned a unique movement rate which most accurately depicts its degree of mobility. Some elements, such as logistics bases, may be set to remain stationary; while others, such as tank companies, may be set to advance several Range Bands. To depict long range fires in enemy defensive scenarios, all enemy elements are assigned a movement rate of zero to reflect the relatively static nature of Stage two of AirLand Operations.

*e. Command and Control*

The only command and control decision element represented by the model is the Commander's Kill Criteria, which is the minimum percent of each enemy system which must be destroyed during each phase of the long range fires battle.

*f. Intelligence and Target Acquisition*

The model reflects the advanced acquisition technology which AirLand Operations is predicated upon. The enemy elements input by the user are the focus

of all Corps target acquisition efforts. Hence, they are assumed to be accurately located given our advanced acquisition capabilities and susceptible to attack by any weapon/munition in range.

*g. Engagement and Attrition*

(1) *Linearity of Massed Fires.* Both the engagement of enemy forces and the attrition of friendly weapons are treated as linear processes. The key to maximizing the effects of indirect artillery fire against the enemy is achieving surprise. By putting as much "steel on target" as possible all at once, we catch the enemy when he is most vulnerable and can achieve devastating results. In order to achieve these effects, the artillery employs a technique termed "Massing Fires." Massing Fires is attacking a target with fires from several different units simultaneously. It is coordinated so all of the rounds impact on the enemy at the exact same time. Each round can be expected to have the same effect. The effects of Massed Fires are therefore linear in nature, with the total effects of an attack linearly dependent upon the type and quantity of munitions used. This is normally the technique employed by corps units providing Long Range Fires in support of the Preparation and Establishing phases of AirLand Operations.

The alternate technique is termed "Volley Fire," and is normally employed when fewer units are available to attack a target. Attacking by Volley Fire is firing several times in succession at the same target. It normally requires fewer firing units, but is less effective because it gives the enemy the opportunity to take protective cover from the shrapnel or move out of the targeted location.

By employing Massed Fires, we achieve much greater effectiveness. By modeling Massed Fires, we are able to model the effects of the long range artillery linearly and avoid the case of the non-linear effects of Volley Fire which is more characteristically employed by artillery units supporting maneuver units with short range, Close-Supporting Fires during the Decisive Operations phase of AirLand Operations.

(2) *Linearity of Aggregated Engagements.* In addition to modeling the natural linearity of Massed Fires, the aggregated approach employed in this model also focuses upon the overall linear effects of artillery upon the entire enemy force. The Artillery Attack Model aggregates all engagements by target type, rather than treating each engagement individually. While it is not reasonable to expect twice the missions fired at a given target to have twice the effect, it is reasonable to expect separate attacks on two individual targets to have twice the effect of either conducted alone [Ref. 4:p.11]. The model considers engagements as a series of individual attacks against individual targets, and treats them in the aggregate.

(3) *Effects Construct.* The model uses an Effects construct which combines the Probability of hitting a target and the Probability of killing a target given that it is hit. Each type of munition is fired from a specific associated weapon and is able to destroy a specified fraction of each type of enemy system. This construct fits the aggregated structure of the model and the test data being generated by USAFAS in its testing of the developmental weapon systems.

(4) *Attrition.* A weapon can be used to attack any enemy system whose range is less than the weapon's Max Range. As weapons fire, they receive counterfire from the enemy and are attrited based upon the number of missions they fire and a Loss Rate associated with the munition and the range of the targets. The more missions a weapon fires, the more likely that it is detected by enemy target acquisition radar and the more losses it sustains. The closer the weapon is to the targets, the higher the Loss Rate.

#### *h. Logistics*

The overall focus of the study is to determine how many of each weapon system and type of munition to produce and stock in the inventory. This is dependent upon the number of enemy forces on the battlefield and how many of them must be destroyed. This in turn drives the number of munitions expended which determines the number of weapons required, based upon the Rate of Fire for each weapon.

Each weapon and munition has an associated Production Cost and Operating and Support Costs (O&S). Weapon Operating and Support Costs are a function of both time (number of Phases) deployed on the battlefield and amount of use (number of missions fired). Munition Operating and Support Costs are only a function of time since munitions can only be "used" once, and the cost of their use is captured by their Production Cost.

#### *i. Approach Summary*

While not representing the aspects of combat processes with the detail of a high resolution model, this approach incorporates the major elements of the Long

Range Fires Battle in a straightforward, highly flexible model construct which can be readily applied by USAFAS to the future force mix problem.

## **B. ASSUMPTIONS AND SIMPLIFICATIONS**

1. The Operational Scenario can be accurately represented by the structure of the user input Target Array and target movement construct.
2. Target priority values are implicitly assigned by the Commander's Kill Criteria for each type of Target.
3. Meeting the Commander's Kill Criteria for all types of Targets equates to mission accomplishment for Long Range Fires, without regard for what specific targets are killed.
4. Friendly units have perfect acquisition of all enemy systems in the Corps area of the battlefield.
5. There is no difference between day and night Long Range Fires.
6. All fire missions are Fire for Effect without adjusting onto the Target.
7. All Targets are attacked with Massed Fires, not a series of volleys.
8. Targets do not assume different protective postures during the battle.
9. Friendly attrition due to enemy counterfire is a function of the number of missions fired and the range to the Targets.
10. There are no resupply constraints incorporated into the model. The model allows the resupply of all the weapons and munitions required to accomplish the mission.
11. The attacking weapon systems move an integer number of Range Bands per Phase.
12. The model aggregates weapons, munitions, and targets, and uses average engagement rates to represent the total results of individual engagements.
13. Systems are not sub-grouped together into individual tactical units.
14. The model employs a low resolution approach to combat modeling.

## C. DATA

### 1. Source

The model was developed for the Directorate of Combat Developments (DCD), US Army Field Artillery School, Fort Sill, Oklahoma. DCD is responsible for the development and evaluation of the new long range artillery systems. Many of these systems are currently being tested. Their performance data is classified and their cost data is unknown. For the systems still under development, both elements of data are unknown.

In order to validate the model, we used a notional set of Test Case Data in order to keep the process unclassified. The results are presented in Chapter IV. The actual classified data will only be used by DCD at FT Sill.

### 2. Elements

#### a. *Friendly Force*

- (1) *Types of Weapons and Munitions Available.*
- (2) *Production and Operating and Support Costs.*
- (3) *Number of Battle Phases Being Modeled.*
- (4) *Number of Range Bands Being Modeled.*
- (5) *Commander's Kill Criteria.*
- (6) *Weapons / Munitions Effects (Lethality).*
- (7) *Weapons / Munitions Max Range.*
- (8) *Weapons / Munitions Operational Mode Maximum Rate of Fire.*

**b. *Enemy Force***

- (1) *Types of Enemy Systems (Targets).*
- (2) *Initial Array of Targets (Start of Phase 1):*
  - Number
  - Location (Range Band)
  - Mobility Index
- (3) *New Targets Deploying After Phase 1.*
- (4) *Enemy Counterfire Effectiveness.*

### III. ARTILLERY ATTACK MODEL LP FORMULATION

#### A. INTRODUCTION

This chapter presents the mathematical formulation of the Artillery Attack Model. The model is a Minimum Cost Linear Programming formulation. The formulation is presented in the Naval Postgraduate School Format.

#### B. INDICES

##### 1. Type of Weapon System - w

###### a. *HIP*

Paladin Improved Howitzer.

###### b. *MLRS*

Multiple Launch Rocket System.

##### 2. Type of Munition - m

###### a. *For HIP*

- (1) *DPICMH*. Dual Purpose Improved Conventional Munitions.
- (2) *HE*. High Explosive Projectile.
- (3) *SADARMH*. Sense and Destroy Armor.
- (4) *TGP*. Terminally Guided Projectile.

**b. For MLRS**

- (1) **ATACMSI.** Army Tactical Missile System Block I.
- (2) **ATACMSII.** Army Tactical Missile System Block II.
- (3) **DPICMM.** Dual Purpose Improved Conventional Munitions.
- (4) **SADARMM.** Sense and Destroy Armor.
- (5) **TGW.** Terminally Guided Warhead.

**3. Type of Target (Enemy System) - t**

**a. ARTY**

Field Artillery Battery.

**b. C3**

Command, Control, Communications Element.

**c. MRC**

Motorized Rifle Company.

**d. TANK**

Tank Company.

**4. Battle Time Phase - p**

**a. 1**

Phase 1 - 1st hour of battle.

**b. 2**

Phase 2 - 2nd hour of battle.

**c. 3**

Phase 3 - 3rd hour of battle.

**5. Target Range Band - r**

**a. 1**

Target located 00 - 30 KM away.

**b. 2**

Target located 30 - 60 KM away.

**c. 3**

Target located 60 - 90 KM away.

**d. 4**

Target located 90 - 120 KM away.

**C. DATA**

**1. DISTANCE<sub>t</sub>**

Number of Range Bands Target t advances per Phase.

**2. EFFECTS<sub>w,m,t</sub>**

Weapon w / Munition m effects against Target type t (Number of Tgts destroyed per round of munition).

**3. FIRERATE<sub>w,m</sub>**

Weapon w / Munition m max Operational Mode long-term sustained rate of fire (Rounds of munition per Phase).

**4.  $KILPERCENT_{t,r}$**

Commander's Kill Criteria for Target  $t$  at Range  $r$  (% Target  $t$  Range  $r$  killed each Phase).

**5.  $LOSSRATE_{w,m,r}$**

Loss Rate of Weapon  $w$  firing Munition  $m$  at targets at Range  $r$  due to counterfire (# Weapons attrited per round of munition  $m$  fired).

**6.  $MAXRANGE_{w,m}$**

Max range for Weapon  $w$  / Munition  $m$  (Range Band number).

**7.  $MOCOST_m$**

Munition  $m$  O&S Cost per Phase on battlefield (Thousands of dollars).

**8.  $MPCOST_m$**

Munition  $m$  Production Cost (Thousands of dollars).

**9.  $NEWTGTS_{t,p,r}$**

Number of new Targets of type  $t$  deployed onto battlefield at Range  $r$  during Phase  $p$ .

**10.  $WOCOSTM_w$**

Weapon  $w$  O&S Cost per round of munition fired (Thousands of dollars).

**11.  $WOCOSTP_w$**

Weapon  $w$  O&S Cost per Phase on battlefield (Thousands of dollars).

**12.  $WPCOST_w$**

Weapon  $w$  Production Cost (Thousands of dollars).

## D. VARIABLES

### 1. $EXCESSM_{m,p}$

Number of Munition m remaining at end of Phase p.

### 2. $EXCESSW_{w,p}$

Number of Weapon w remaining at end of Phase p.

### 3. $MPROD_{m,p}$

Number of Munitions m required to Produce and Resupply for Phase p.

### 4. $TGTS_{t,p,r}$

Total Targets t during Phase p at Range r (Before losses).

### 5. $TOTCOST$

Total Cost of Weapons and Munitions (Over entire battle).

### 6. $WPROD_{w,p}$

Number of Weapons w required to Produce and Resupply for Phase p.

### 7. $X_{w,m,t,p,r}$

Number Missions (Rounds) fired by all Weapons w with Munition m against Target t at Range r during Phase p.

## E. MATHEMATICAL FORMULATION

MINIMIZE TOTAL COST =

$$\begin{aligned}
 & \left[ \sum_v \sum_p (WPROD_{v,p} * MPCOST_v) \right] + \\
 & \sum_v \left[ \sum_{p=1}^k WOCOSTP_v * \left( \sum_{i=1}^p WPROD_{v,i} - \sum_{i=1}^{p-1} \left( \sum_M \sum_T \sum_x X_{v,M,T,i,x} * LOSSRATE_{v,M,x} \right) \right) \right] + \\
 & \sum_v \left[ \sum_M \sum_T \sum_p \sum_x (X_{v,M,T,p,x} * WOCOSTM_v) \right] + \\
 & \left[ \sum_M \sum_p (MPROD_{M,p} * MPCOST_M) \right] + \\
 & \sum_M \left[ \sum_{p=1}^k WOCOST_M * \left( \sum_{i=1}^p MPROD_{M,i} - \sum_{i=1}^{p-1} \left( \sum_v \sum_T \sum_x X_{v,M,T,i,x} \right) \right) \right]
 \end{aligned}$$

SUBJECT TO :

$$\begin{aligned}
 1. \quad TGTS_{t,p,x} &= [ TGTS_{t,p-1,x+DISTANCE(t)} ] - \\
 & \left[ \sum_v \sum_M (X_{v,M,t,p-1,x+DISTANCE(t)} * EFFECTS_{v,M,t}) \right] + NEXTGTS_{t,p,x} , \quad \forall (t,p,x)
 \end{aligned}$$

$$2. \quad \left[ \sum_v \sum_M (X_{v,M,t,p,x} * EFFECTS_{v,M,t}) \right] \geq [ TGTS_{t,p,x} * KILPERCENT_{t,x} ] , \quad \forall (t,p,x)$$

$$3. \quad \left[ \sum_w \sum_x ( X_{w, m, t, p, x} * \text{EFFECTS}_{w, m, t} ) \right] \leq \text{TGTS}_{t, p, x} , \quad \forall (t, p, x)$$

$$4. \quad \text{NPROD}_{w, p} \geq \left[ \sum_x \left( \sum_t \sum_x X_{w, m, t, p, x} / \text{FIRERATE}_{w, m} \right) \right] + \\ \left[ \sum_x \sum_t \sum_x X_{w, m, t, p, x} * \text{LOSSRATE}_{w, m, x} \right] - \text{EXCESSW}_{w, p-1} , \quad \forall (w, p)$$

$$5. \quad \text{MPROD}_{m, p} \geq \left[ \sum_w \sum_x \sum_x X_{w, m, t, p, x} \right] - \text{EXCESSM}_{m, p-1} , \quad \forall (m, p)$$

$$6. \quad \text{EXCESSW}_{w, p} = \left[ \sum_{i=1}^p \text{NPROD}_{w, i} \right] - \\ \left[ \sum_{i=1}^p \left( \sum_w \sum_x \sum_x X_{w, m, t, i, x} * \text{LOSSRATE}_{w, m, x} \right) \right] , \quad \forall (w, p)$$

$$7. \quad \text{EXCESSM}_{m, p} = \\ \left[ \sum_{i=1}^p \text{MPROD}_{m, i} \right] - \left[ \sum_{i=1}^p \left( \sum_w \sum_x \sum_x X_{w, m, t, i, x} \right) \right] , \quad \forall (m, p)$$

## 1. Objective Function

MINIMIZE :

TOTAL COST = WEAPONS COST + MUNITIONS COST

- Production cost	- Production Cost
- Operating & Support	- Operating & Support

**TOTAL COST =**

**a. WEAPONS PRODUCTION COST:**

$$\left[ \sum_w \sum_p (WPROD_{w,p} * WPCOST_w) \right] +$$

**b. WEAPONS O/S COST (TIME/PHASE COST):**

$$\sum_w \left[ \sum_{p=1}^k WOCOSTP_w * \left( \sum_{i=1}^p WPROD_{w,i} - \sum_{i=1}^{p-1} \left( \sum_M \sum_T \sum_R (X_{w,M,i,T} * LOSSRATE_{w,M,i}) \right) \right) \right] +$$

**c. WEAPONS O/S COST (MISSION COST):**

$$\sum_w \left[ \sum_M \sum_T \sum_p \sum_R (X_{w,M,p,T} * WOCOSTM_w) \right] +$$

**d. MUNITIONS PRODUCTION COST:**

$$\left[ \sum_m \sum_p (MPROD_{m,p} * MPCOST_m) \right] +$$

**e. MUNITIONS O/S COST (TIME/PHASE COST):**

$$\sum_m \left[ \sum_{p=1}^k MOCOST_m * \left( \sum_{i=1}^p MPROD_{m,i} - \sum_{i=1}^{p-1} \left( \sum_w \sum_T \sum_R X_{w,M,i,T} \right) \right) \right]$$

*a. Weapons Production Cost*

The Weapons Production Cost is the sum of the total production costs for each type of weapon system.

*b. Weapons Operating and Support Cost - for Time Phases*

The Weapons O&S Cost for Time Phases captures the O&S costs (personnel, maintenance, fuel) associated with operating a weapon system for a phase of the battle independent of the number of missions it fires. It is determined by:  $(\text{Weapon Inventory}_{w,p}) * (\text{O\&S Cost per Phase})_w$  for each weapon and each phase.  $\text{Weapon Inventory}_{w,p}$  is the total weapons produced minus the number lost up to that phase of battle. The number of weapons systems lost in a phase is a function of the missions fired by that type of system and an associated loss-rate.

*c. Weapons Operating and Support Cost - for Missions Fired*

The Weapons O&S Cost for Missions Fired captures the O&S costs associated with firing a weapon system. It is determined by:  $(\text{Total Missions Fired by Weapon System})_w * (\text{O\&S Cost per Mission})_w$  for each weapon system over the entire battle.

*d. Munitions Costs*

Munitions costs are determined in the same manner except there is no O&S Cost for missions fired since munitions are used only once and this is captured by the Munition Production Cost. The munitions inventory is the number produced minus the number fired.

## 2. Constraints

### SUBJECT TO :

#### a. Determine Number Targets - For Each $(t,p,r)$

$$TGTS_{t,p,r} = [TGTS_{t,p-1,r} + DISTANCE_{t,r}] - \left[ \sum_w \sum_M (X_{w,M,t,p-1,r} * DISTANCE_{t,r} * EFFECTS_{w,M,t}) \right] + NEWTGTS_{t,p,r}$$

The model determines the number of each type of target deployed within each range band of the battlefield for each phase of the battle. The number of Targets<sub>t,p,r</sub> is the number of enemy elements of type t which survived the previous phase of battle and advanced forward into range band r, plus any NEWTGTS<sub>t,p,r</sub> which deploy onto range band r of the battlefield during phase p. This is the inventory of targets present prior to target kills being assessed. The number of targets advancing into a range band is dependent upon the DISTANCE<sub>t,r</sub> parameter assigned to each type of target. The number of targets killed is a function of the munitions fired at that type of target and the EFFECTS<sub>t,p,r</sub> parameter assigned to each type of munition. In addition to defining the initial array of enemy forces and follow-on echelons, the parameter NEWTGTS<sub>t,p,r</sub> has the flexibility to be used to introduce airborne and special forces elements anywhere onto the battlefield.

#### b. Meet Commander's Kill Criteria - For Each $(t,p,r)$

$$\left[ \sum_w \sum_M (X_{w,M,t,p,r} * EFFECTS_{w,M,t}) \right] \geq [ TGTS_{t,p,r} * KILPERCENT_{t,r} ]$$

The model optimally determines which targets to attack with the types of weapons and munitions available. It fires the number of missions necessary to kill the required percentage of each type of target specified by the maneuver commander. The model determines where and when to attack targets based upon weapon ranges and effects, as well as counterfire loss-rate<sup>c</sup>, in order to minimize the cost of achieving the commander's kill criteria.

*c. Limit Engagements to Existing Targets - For Each (t,p,r)*

$$\left[ \sum_w \sum_m (X_{w,m,t,p,r} * EFFECTS_{w,m,t}) \right] \leq TGTS_{t,p,r}$$

The long-range artillery fires cannot kill more targets in a range band, than the enemy has deployed within that range band of the battlefield.

*d. Determine Weapon Production/Resupply Requirements - For Each (w,p)*

$$WPROD_{w,p} \geq$$

$$\left[ \sum_m \left( \sum_t \sum_r X_{w,m,t,p,r} / FIRERATE_{w,m} \right) \right] + \left[ \sum_m \sum_t \sum_r X_{w,m,t,p,r} * LOSSRATE_{w,m,r} \right] - EXCESSW_{w,p-1}$$

The model determines the number of each type of weapon system required each phase to deliver the munitions necessary to kill the enemy and to cover the losses to enemy counterfire. It then subtracts the number of weapons remaining from the previous phase to determine the WPROD<sub>w,p</sub>. The number required is a function of the number of missions to be fired and the weapon's operational mode

maximum rate of fire. Counterfire losses are a function of the number of missions fired and the LOSSRATE<sub>w,m,r</sub> associated with firing the munition at targets at range r.

e. *Determine Munition Production/Resupply Requirements - For Each (m,p)*

$$MPROD_{m,p} \geq \left[ \sum_w \sum_T \sum_R X_{w,m,t,p,r} \right] - EXCESSM_{m,p-1}$$

The model determines the number of each type of munition required each phase to kill the enemy. It then subtracts the number remaining from the previous phase to determine the MPROD<sub>m,p</sub>.

f. *Determine Number Weapons Remaining End of Each Phase - For Each (w,p)*

$$EXCESSW_{w,p} = \left[ \sum_{i=1}^P WPROD_{w,i} \right] - \left[ \sum_{i=1}^P \left( \sum_M \sum_T \sum_R X_{w,m,t,i,r} * LOSSRATE_{w,m,r} \right) \right]$$

The model determines the number of weapons of each type which remain at the end of each phase by subtracting the total number of weapons lost from the total number produced, through that phase of battle.

g. *Determine Number Munitions Remaining End of Each Phase - For Each (m,p)*

$$EXCESSM_{m,p} = \left[ \sum_{i=1}^P MPROD_{m,i} \right] - \left[ \sum_{i=1}^P \left( \sum_w \sum_T \sum_R X_{w,m,i,r} \right) \right]$$

The model determines the number of munitions of each type which remain at the end of each phase by subtracting the total number of munitions fired from the total produced, through that phase of battle.

## **IV. APPLICATION OF THE ARTILLERY ATTACK MODEL**

### **A. TEST CASE OPERATIONAL SCENARIO**

The purpose of this chapter is to apply the model to a Test Data Case and examine the results. The Test Case presents an Operational Scenario in which a US Corps is defending against a Soviet Combined Arms Army (CAA), attacking in Central Europe. In light of current political changes in the Soviet Union, this appears to be an unlikely scenario. However, it presents a good example of how the model works within the context of a threat scenario with which all military analysts are familiar. The CAA is configured with three Motorized Rifle Divisions and one Tank Division. The model only depicts maneuver elements, artillery units, and tactical operations centers (C3 elements) for regiments and above. The enemy force is arrayed in March Formation in preparation for offensive operations. The enemy Order of Battle is depicted below in Figure 1.

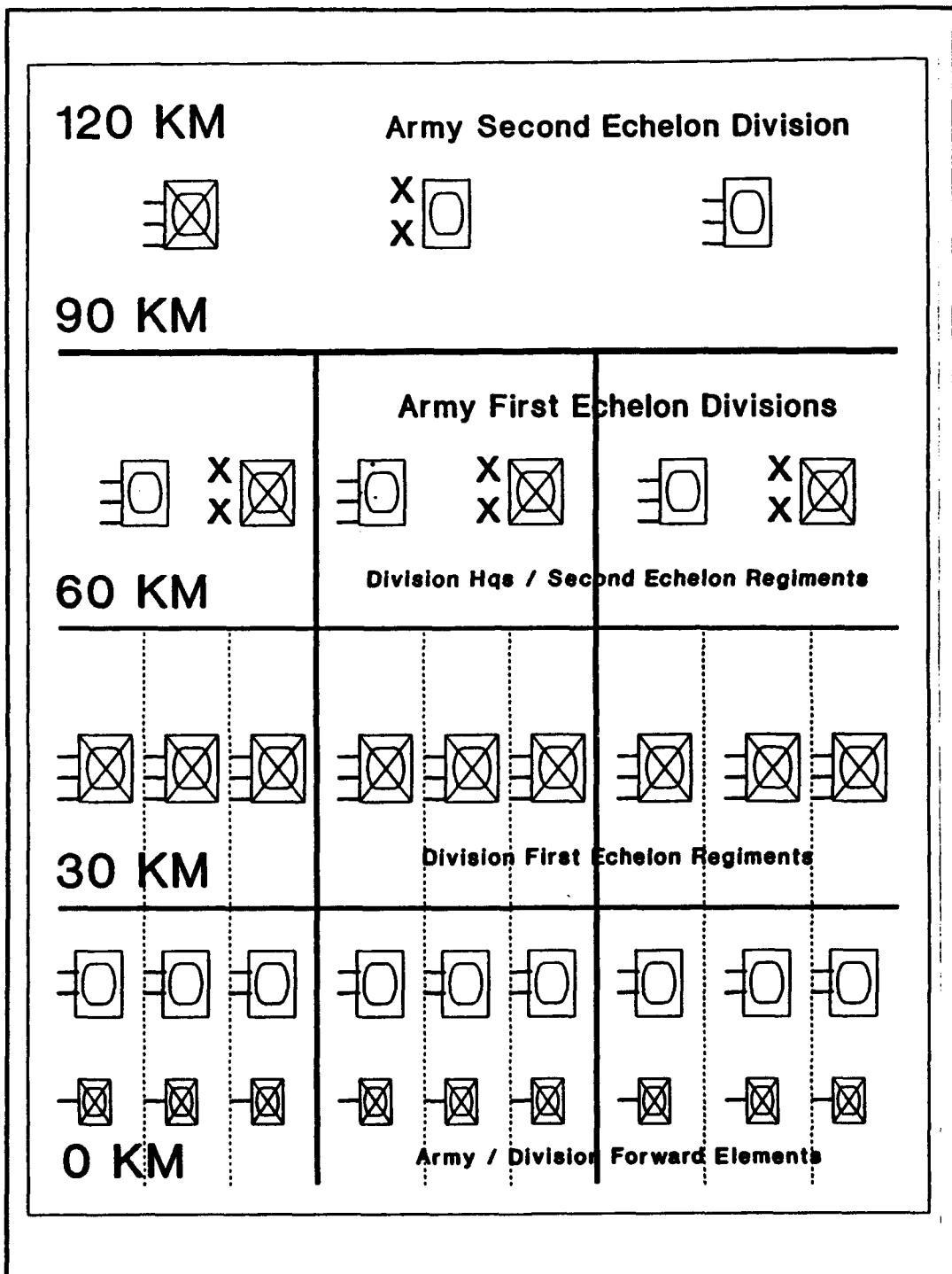


Figure 1 Test Case Combined Arms Army Order of Battle

## B. TEST CASE INPUT DATA SET

### 1. Enemy Forces

The number and location of the initial enemy forces are based upon the Order of Battle presented in Figure 1, and represented in the model by the following initial target array values for Parameter  $\text{NEWTGTS}_{t,p=1,r}$ :

ENEMY FORCES DEPLOYED START OF PHASE 1 :				
TARGET TYPE :	RANGE 1	RANGE 2	RANGE 3	RANGE 4
ARTILLERY BATTERIES	9	66	9	24
MOTORIZED RIFLE COMPANIES	9	72	9	12
TACTICAL OPNS CTRS	0	9	6	6
TANK COMPANIES	27	0	27	30

For the Test Case, there are no new targets appearing after Phase 1. Therefore Parameter  $\text{NEWTGTS}_{t,p=2,r}$  and  $\text{NEWTGTS}_{t,p=3,r}$  matrices are both equal to zero.

### 2. Movement of Enemy Forces

The movement of the offensive forces is represented by the following values for the Parameter  $\text{DISTANCE}_t$ . Tactical Operations Centers are assigned a movement parameter equal to zero in order to demonstrate the implementation of stationary targets.

ENEMY FORCE RATE OF MOVEMENT :		
TARGET TYPE :	ACTUAL DISTANCE:	PARAMETER DISTANCE <sub>T</sub> :
ARTILLERY BATTERIES	30 KM	1
MOTORIZED RIFLE COMPANIES	30 KM	1
TACTICAL OPERATIONS CENTERS	0 KM	0
TANK COMPANIES	30 KM	1

### 3. Commander's Kill Criteria

The percent of each target which the maneuver commander requires to be killed is outlined in the following values for KILPERCENT<sub>tr</sub> :

PERCENTAGE OF ENEMY FORCES REQUIRED TO BE KILLED :				
TARGET TYPE :	RANGE 1	RANGE 2	RANGE 3	RANGE 4
ARTILLERY BATTERIES	.8	.8	.5	.5
MOTORIZED RIFLE COMPANIES	.8	.4	.1	.1
TACTICAL OPERATIONS CENTERS	.6	.8	.8	.8
TANK COMPANIES	.9	.6	.3	.1

#### 4. Artillery Effectiveness

The lethality of each weapon/munition combination against each type of enemy element is outlined in the following table of values for the Parameter  $EFFECTS_{w,m,t}$  :

EFFECTS OF INDIVIDUAL ROUND OF MUNITION AGAINST TARGETS					
WEAPON SYSTEM :	MUNITION TYPE :	TARGET TYPE :			
		ARTY	MRC	TOC	TANK
HIP	DPICM	.05	.08	.08	.05
HIP	HE	.03	.07	.07	.03
HIP	SADARM	.07	.10	.10	.07
HIP	TGP	.08	.12	.12	.08
MLRS	ATACMS I	.80	1.0	1.0	1.0
MLRS	ATACMS II	.90	1.0	1.0	1.0
MLRS	DPICM	.12	.15	.13	.10
MLRS	SADARM	.13	.16	.15	.12
MLRS	TGW	.90	1.0	.90	.80

## 5. Artillery Rate of Fire

The Operational Mode maximum rate of fire for each weapon/munition combination input for Parameter  $\text{FIRERATE}_{w,m}$  is :

MAX RATE OF FIRE FOR INDIVIDUAL WEAPON/MUNITION :					
WEAPON	MUNITION				
HIP	DPICM	HE	SADARM	TGP	
	3	3	3	3	
MLRS	ATACMSI	ATACMSII	DPICM	SADARM	TGW
	6	6	18	18	6

## 6. Artillery Maximum Range

The maximum range of each weapon/munition is outlined below in the table values for Parameter  $\text{MAXRANGE}_{w,m}$  :

MAXIMUM RANGE OF WEAPON/MUNITION :					
WEAPON	MUNITION				
HIP	DPICM	HE	SADARM	TGP	
	1	1	1	1	
MLRS	ATACMSI	ATACMSII	DPICM	SADARM	TGW
	4	4	2	2	2

## 7. Counterfire Rate of Enemy Artillery

As our artillery fires, the enemy target acquisition radar attempts to locate our units and send counter-battery fire to destroy our artillery elements. The resulting friendly attrition is a function of the values input for Parameter LOSSRATE<sub>w,m,r</sub>:

COUNTERFIRE LOSS RATE PER INDIVIDUAL ROUND FIRED :					
WEAPON SYSTEM :	MUNITION TYPE :	RANGE 1	RANGE 2	RANGE 3	RANGE 4
HIP	DPICM	.04	.00	.00	.00
HIP	HE	.04	.00	.00	.00
HIP	SADARM	.04	.00	.00	.00
HIP	TGP	.04	.00	.00	.00
MLRS	ATACMS I	.10	.05	.01	.01
MLRS	ATACMS II	.10	.05	.01	.01
MLRS	DPICM	.02	.01	.00	.00
MLRS	SADARM	.02	.01	.00	.00
MLRS	TGW	.01	.05	.00	.00

## 8. Weapon Costs

WEAPON COSTS (Thousands of Dollars) :			
WEAPON SYSTEM	PRODUCTION COST	O / S COST (PHASE)	O / S COST (MISSIONS)
HIP	200	10	1
MLRS	2000	100	10

## 9. Munition Costs

MUNITION COSTS (Thousands of Dollars) :		
MUNITION	PRODUCTION COST	O / S COST (PHASE)
ATACMS I	200.0	0.5
ATACMS II	400.0	0.5
DPICM (HIP)	0.8	0.1
DPICM (MLRS)	5.0	0.4
HE	0.3	0.1
SADARM (HIP)	10.0	0.2
SADARM (MLRS)	20.0	0.4
TGP	10.0	0.2
TGW	100.0	0.4

## **C. MODEL SOLUTION PROCEDURE**

### **1. Applying the General Algebraic Modeling System**

In order to utilize the computer to solve the Artillery Attack Model, the Linear Programming model formulation was coded in the General Algebraic Modeling System (GAMS) programming language. GAMS is a high level language used to formulate mathematical models with algebraic statements which can be easily modified and easily transported from one computer environment to another [Ref. 6]. It is an ideal tool to meet the flexibility and exportability requirements of USAFAS. The Artillery Attack Model GAMS computer formulation is presented in Appendix A.

### **2. Applying the Zero/One Optimization Method XMP Solver**

Once the model was encoded in the GAMS programming language, it was solved utilizing the solution algorithm of the Zero/One Optimization Method (ZOOM) Solver. ZOOM is a Fortran based system used to solve Mixed Integer Programming problems. GAMS/ZOOM first solves the problem as a Linear Program using the XMP Linear Programming library. It then uses the Pivot and Complement heuristic, as well as, the Branch and Bound search procedure to find an integer solution.[Ref. 6:p. 225]

## **D. TEST CASE OUTPUT / RESULTS**

Solving the model using GAMS/ZOOM generated the GAMS Listing file "AAM LISTING" which is presented in Appendix B. Although AAM GAMS is coded as a Mixed Integer Problem (MIP), solving for the integer solution takes an inordinate amount of central processor time (CPU). Solving the problem as a Relaxed Mixed Integer Problem (RMIP), not only takes a fraction of the CPU time, but also yields a very good real number approximation.

The Test Case problem was first solved using RMIP and then modified to display an integer equivalent solution using the GAMS CEIL function which rounds up to the next higher integer. This yields the most "conservative" approximation of the missions, weapons, and munitions required for the given scenario. The total cost for both the real and integer set of missions, weapons, and munitions are displayed at the bottom of the Listing File. The specific results are outlined below.

1. **Part I - Optimal Weapon / Munition Mix**

a. **Weapons Required**

NUMBER OF WEAPONS REQUIRED :				
WEAPON SYSTEM :	PHASE 1	PHASE 2	PHASE 3	TOTAL
HIP	23	0	0	23
MLRS	38	0	0	38

*b. Munitions Required*

NUMBER OF MUNITIONS REQUIRED :				
MUNITION TYPE :	PHASE 1	PHASE 2	PHASE 3	TOTAL
ATACMS I	68	19	1	88
ATACMS II	0	0	0	0
DPICM (HIP)	0	54	48	102
DPICM (MLRS)	0	231	33	264
HE	0	0	0	0
SADARM (HIP)	0	0	0	0
SADARM (MLRS)	0	0	0	0
TGP	60	0	0	60
TGW	106	36	29	171

## 2. Part II - Optimal Target Allocation

### a. Target Type - Artillery Batteries

MUNITIONS USED TO ATTACK - ARTILLERY BATTERIES :				
MUNITION TYPE :	PHASE 1	PHASE 2	PHASE 3	TOTAL
ATACMS I	21	8	0	29
ATACMS II	0	0	0	0
DPICM (HIP)	0	0	0	0
DPICM (MLRS)	0	0	0	0
HE	0	0	0	0
SADARM (HIP)	0	0	0	0
SADARM (MLRS)	0	0	0	0
TGP	0	0	0	0
TGW	67	16	7	90

**b. Target Type - Motorized Rifle Companies**

MUNITIONS USED TO ATTACK - MOTOR. RIFLE COMPANIES :				
MUNITION TYPE :	PHASE 1	PHASE 2	PHASE 3	TOTAL
ATACMS I	3	2	0	5
ATACMS II	0	0	0	0
DPICM (HIP)	0	54	48	102
DPICM (MLRS)	0	222	31	253
HE	0	0	0	0
SADARM (HIP)	0	0	0	0
SADARM (MLRS)	0	0	0	0
TGP	60	0	0	60
TGW	32	6	0	38

c. *Target Type - Tactical Operations Centers*

MUNITIONS USED TO ATTACK - TACTICAL OPERATIONS CENTERS :				
MUNITION TYPE :	PHASE 1	PHASE 2	PHASE 3	TOTAL
ATACMS I	10	2	2	14
ATACMS II	0	0	0	0
DPICM (HIP)	0	0	0	0
DPICM (MLRS)	0	10	2	12
HE	0	0	0	0
SADARM (HIP)	0	0	0	0
SADARM (MLRS)	0	0	0	0
TGP	0	0	0	0
TGW	8	0	0	8

*d. Target Type - Tank Companies*

MUNITIONS USED TO ATTACK - TANK COMPANIES :				
MUNITION TYPE :	PHASE 1	PHASE 2	PHASE 3	TOTAL
ATACMS I	37	9	0	46
ATACMS II	0	0	0	0
DPICM (HIP)	0	0	0	0
DPICM (MLRS)	0	0	0	0
HE	0	0	0	0
SADARM (HIP)	0	0	0	0
SADARM (MLRS)	0	0	0	0
TGP	0	0	0	0
TGW	0	15	24	39

### 3. Part III - Optimal Total Cost

<b>TOTAL COST (Dollars) :</b>
\$ 132,586,600

### 4. Analysis of Model Results

It is interesting to note that the Test Case results indicate that all weapon systems required over the entire three phase battle should be supplied during the initial phase of battle. This makes intuitive sense in view of the fact that there are 45 enemy company sized units already within 30 km at the start of Phase one, and the closer the enemy units are, the higher the percentage that must be killed. Therefore the model expends in Phase 1, over a third of the total munitions required for the entire battle. Given the maximum operational mode weapon rates of fire and the resulting attrition, the weapons required for Phase 1 are sufficient to meet all fire mission requirements for Phase 2 and Phase 3 as well.

## V. CONCLUSIONS

### A. SUMMARY

The Artillery Attack Model provides the Artillery School with a Mixed Integer Linear Programming formulation to assist in determining the optimal (least expensive) weapon/munition force mix and tactical employment of the next generation artillery systems. The model is coded in the GAMS programming language used at USAFAS and employs the standard GAMS/ZOOM solver. The model can be easily modified by the user to incorporate changing tactics or technologies. It provides the flexibility to model the myriad of operational scenarios possible in today's changing political environment. It can also integrate any future weapon/munition technology with supporting or projected performance and support data, as well as, accommodate existing inventories of current weapon systems. The Artillery Attack Model will help ensure that the US Field Artillery is prepared to provide the long range fires so crucial to our success under AirLand Operations - the same consistently accurate and deadly fires which long ago earned it the title "the King of Battle."

### B. RECOMMENDATIONS

#### 1. Suggested Improvements

##### *a. Reconstitution*

Presently, the model does not incorporate the reconstitution capability of units - the repair and return to service of damaged weapon systems. This can be done by designating a certain percentage of enemy targets killed and friendly attrition

losses as damaged rather than destroyed. Currently all target kills and attrition losses are considered catastrophic kills.

*b. Expanded Target Types*

The model could be expanded to represent more enemy Combat Support and Combat Service Support elements such as Air Defense, Engineer, Signal, and Logistics units.

*c. Day / Night Distinction*

If test data suggests degraded target acquisition and engagement at night, then the model could be modified to incorporate a day phase/night phase rotation sequence with separate day and night  $NUMTGTSt_{p,r}$  and  $EFFECTS_{w,m,t}$  data.

*d. PHIT/PKILL Construct*

The model employs a low-resolution approach to modeling the effects of engaging enemy forces, using a fractional kill per round of munition fired. If data were available to determine the probability of hit given accurate target location and the subsequent probability of kill given the target is hit, engagement could be modeled perhaps more precisely using a Bayesian probability methodology.

*e. Incorporate the Non-Linearity of Changing Protective Posture*

Although long range fires are normally massed and the model deals with targets in the aggregate, the Commander's Kill Criteria may dictate that a certain portion of enemy elements are attacked more than once in a phase. This would result in reduced effects as they move either under cover or to an alternate position. In order to capture this possible aspect of battle, the long range fires process could either be

modeled non-linearly or an effectiveness factor could be applied to the EFFECTS<sub>w.m.t</sub>. Parameter based upon the percentage of a given target type engaged during a given phase.

## 2. Follow - On Study

The next logical question to be answered is: "Once we have the weapons and munitions we need, where do we put them?" This is a three step problem:

### a. Input

The determining inputs to the problem are the costs and the scenarios. First we must determine or estimate the costs to pre-position the weapons and munitions at a various forward locations, as well as, the subsequent costs to deploy them from these locations to the battlefield when conflict develops. Costs can be in terms of money and/or deployment time.

Secondly, we must develop target arrays for likely operational scenarios, as well as, the likelihood (probability) of each scenario.

### b. Process

The process involves developing an optimization model which analyzes the weapons/munitions available, the probability of each operational scenario, and the proximity (cost) associated with deploying the necessary artillery inventory from the possible pre-position sites to each theater of operation. in order to determine the Minimum Cost (money or time).

**c. Output**

The follow-on study would determine the Minimum Cost (money or time), pre-deployment scheme for the future artillery inventory, in order for the artillery to best accommodate our increasing reliance upon Rapid-Deployment and Forward Presence.

## APPENDIX A. AAM GAMS PROGRAM

\$TITLE ----- ARTILLERY ATTACK MODEL -----  
\$TITLE - Combined Arms Army - Offensive Scenario -

\*\* ----- GAMS AND DOLLAR CONTROL OPTIONS -----\*\*  
\$OFFUPPER OFFSYMREF OFFSYMLIST

OPTIONS SOLPRINT = OFF , LIMROW = 0, RESLIM = 10000  
OPTIONS OPTCR = 0.1 , LIMCOL = 0 , ITERLIM = 100000  
OPTIONS SYSOUT = OFF ;

\*\* ----- DEFINITIONS AND INPUT DATA -----\*\*

SET W Weapon System / HIP Improved Howitzer  
MLRS Mult Launch Rocket Sys /

M Munition Type /  
FOR HIP:  
DPICMH HIP Dual Pupr Imp Conv  
HE High Explosive  
SADARMH HIP Sense\Destroy Armor  
TGP Term Guided Proj  
  
FOR MLRS:  
ATACMSI Army Tac Missile(DPICM)  
ATACMSII (Longer Range)  
DPICMM MLRS Dual Pupr Imp Conv  
SADARMM MLRS Sense\Destroy Armor  
TGW Term Guided Warhead /

T Target Type /  
ARTY Artillery Battery  
MRC Motorized Rifle Company  
TANK Tank Company  
TOC Reg\Div Tac Ops Center /

P Battle Phase / 1 Hour 1  
2 Hour 2  
3 Hour 3 /

R Target Range / 1 Tgt Between 0 - 30 KM Away  
2 30 - 60  
3 60 - 90  
4 90 -120 /

WCOSTS Wpn Costs / WPCOST Wpn Production Cost  
 WOCOSTP O\S Cost per Battle Phase  
 WOCOSTM O\S Cost per Msn Fired /

MCOSTS Mun Costs / MPCOST Mun Production Cost(Per Rd)  
 MOCOST O\S Cost per Battle Phase/ ;

ALIAS (P,I) ;

PARAMETER DISTANCE(T) # Range Bands Tgt T Moves per Phase  
 / ARTY 1  
 MRC 1  
 TANK 1  
 TOC 0 / ;

TABLE KILPERCENT(T,R) % Tgts Type T Required Killed Range R

	Range 1	Range 2	Range 3	Range 4
	1	2	3	4
ARTY	0.8	0.8	0.5	0.5
MRC	0.8	0.4	0.1	0.1
TANK	0.9	0.6	0.3	0.1
TOC	0.6	0.8	0.8	0.8

TABLE NEWTGTS(T,P,R) # New Tgts Deployed Onto Battlefield  
 at Range R, During Phase P

Phase 1 :		Range 1	Range 2	Range 3	Range 4
		1.1	1.2	1.3	1.4
	ARTY	9	66	9	24
	MRC	9	72	9	12
	TANK	27	0	27	30
	TOC	0	9	6	6
Phase 2 :					
		2.1	2.2	2.3	2.4
	ARTY	0	0	0	0
	MRC	0	0	0	0
	TANK	0	0	0	0
	TOC	0	0	0	0
Phase 3 :					
		3.1	3.2	3.3	3.4
	ARTY	0	0	0	0
	MRC	0	0	0	0
	TANK	0	0	0	0
	TOC	0	0	0	0

TABLE EFFECTS(W,M,T) Munition Effectiveness\Lethality  
(% Tgt T Killed\Rd)

Weapon/Munition:	Target:			
	ARTY	MRC	TANK	TOC
HIP.DPICMH	0.05	0.08	0.05	0.08
HIP.HE	0.03	0.07	0.03	0.07
HIP.SADARMH	0.07	0.10	0.07	0.10
HIP.TGP	0.08	0.12	0.08	0.12
MLRS.ATACMSI	0.80	1.00	1.00	1.00
MLRS.ATACMSII	0.90	1.00	1.00	1.00
MLRS.DPICMM	0.12	0.13	0.10	0.15
MLRS.SADARMM	0.13	0.15	0.12	0.16
MLRS.TGW	0.90	0.90	0.80	1.00

TABLE FIRERATE(W,M) Wpn\Mun Long-Term Sustained  
Rate of Fire (Rds/Phase)

Weapon:	Munition:			
	DPICMH	SADARMH	TGP	HE
HIP	3	3	3	3
MLRS	18	18	6	6

TABLE MAXRANGE(W,M) Max Range of Wpn\Mun Combination  
(range band)

Weapon:	Munition:			
	DPICMH	SADARMH	TGP	HE
HIP	1	1	1	1
MLRS	2	2	2	4

TABLE LOSSRATE(W,M,R) Wpn Rate of Loss to Enemy Counterfire  
(% Wpns Disabled\Destr per Rd Fired)

Munition:	Range 1	Range 2	Range 3	Range 4
HIP.DPICMH	0.04	0.00	0.00	0.00
HIP.HE	0.04	0.00	0.00	0.00
HIP.SADARMH	0.04	0.00	0.00	0.00
HIP.TGP	0.04	0.00	0.00	0.00
MLRS.ATACMSI	0.10	0.05	0.01	0.01
MLRS.ATACMSII	0.10	0.05	0.01	0.01
MLRS.DPICMM	0.02	0.01	0.00	0.00

MLRS.SADARMM	0.02	0.01	0.00	0.00
MLRS.TGW	0.10	0.05	0.00	0.00

TABLE WPNCOSTS(W,WCOSTS) (Thousands of Dollars)

\* Weapon:

	WPCOST	WOCOSTP	WOCOSTM
HIP	200	10	1
MLRS	2000	100	10

TABLE MUNCOSTS(M,MCOSTS) (Thousands of Dollars)

\* Munition:

	MPCOST	MOCOST
ATACMSI	200.0	0.5
ATACMSII	400.0	0.5
DPICMH	0.8	0.1
DPICMM	5.0	0.4
HE	0.3	0.1
SADARMH	10.0	0.2
SADARMM	20.0	0.4
TGP	10.0	0.2
TGW	100.0	0.4

\*\* ARTILLERY ATTACK MODEL \*\*

POSITIVE  
VARIABLES

EXCESSM(M,P) # Mun M Remaining End Phase P

EXCESSW(W,P) # Wpn W Remaining End Phase P

TGTS(T,P,R) Total as T \ Phase P \ Range R  
on Battlefield (Before Losses)

INTEGER  
VARIABLES

MPROD(M,P) # Mun M Produced\Resupplied for Phase P

WPROD(W,P) # Wpn W Produced\Resupplied for Phase P

X(W,M,T,P,R) # Mms Fired by All Wpn W\ Mun M Combo ;  
at Tgt T \ Phase P \ Range R

\* SET BOUNDARIES

MPROD.LO(M,P) = 0 ;

MPROD.UP(M,P) = 400 ;

```

WPROD.LO(W,P) = 0      ;
WPROD.UP(W,P) = 50      ;

X.LO(W,M,T,P,R) = 0      ;
X.UP(W,M,T,P,R) = 400      ;

* Set Model Not to Attack Targets Out of Range:
  X.FX(W,M,T,P,R)$ORD(R) GT MAXRANGE(W,M) = 0      ;
* Set Model Not to Use Incompatible Wpn\ Mun Combos:
  X.FX(W,M,T,P,R)$EFFECTS(W,M,T) EQ 0 = 0      ;

VARIABLE    TOTCOST      Total Cost of Weapons and Munitions      ;
*           (Over Entire Battle)

```

EQUATIONS OBJ Calculate Total Cost of Wpns and Muns

```

NUMTGT(T,P,R) Determine # Tgts T at Range R Phase P
MINKILLS(T,P,R) Meet Kill Crit Tgt T Phase P Range R
MAXKILLS(T,P,R) Limit Engagements to Existing Tgts
WPNPROD(W,P) Determine Wpn Prod\Resupply Requirements
MUNPROD(M,P) Determine Mun Prod\Resupply Requirements
SETEXCESSW(W,P) Determine # Wpn W Remaining End Phase P
SETEXCESSM(M,P) Determine # Mun M Remaining End Phase P ;

```

\* Minimize Total Cost :

```

OBJ..  TOTCOST =E= SUM((W,P), WPNCOSTS(W,'WPCOST') * WPROD(W,P)) +
SUM((W,P), WPNCOSTS(W,'WOCOSTP') *
(SUM(I$ORD(I) LE ORD(P)), WPROD(W,I))-
SUM(I$ORD(I) LE (ORD(P)-1)),SUM((M,T,R),
X(W,M,T,I,R) * LOSSRATE(W,M,R)))) + 

SUM((W,M,T,P,R), WPNCOSTS(W,'WOCOSTM') *
X(W,M,T,P,R)) + 

SUM((M,P), MUNCOSTS(M,'MPCOST') * MPROD(M,P)) +
SUM((M,P), MUNCOSTS(M,'MOCOST') *
(SUM(I$ORD(I) LE ORD(P)),MPROD(M,I)) -
SUM(I$ORD(I) LE (ORD(P)-1)), SUM((W,T,R),
X(W,M,T,I,R)))) ;

```

\* Subject To :

NUMTGTS(T,P,R).. TGTS(T,P,R) =E= TGTS(T,P-1,R + DISTANCE(T)) -  
SUM((W,M), X(W,M,T,P-1,R + DISTANCE(T)) \*  
EFFECTS(W,M,T)) + NEWTGTS(T,P,R) ;

MINKILLS(T,P,R).. SUM((W,M), X(W,M,T,P,R) \*  
EFFECTS(W,M,T)) =G=  
TGTS(T,P,R) \* KILPERCENT(T,R) ;

MAXKILLS(T,P,R).. SUM((W,M), X(W,M,T,P,R) \* EFFECTS(W,M,T)) =L=  
TGTS(T,P,R) ;

WPNPROD(W,P).. WPROD(W,P) =G=  
SUM(M\$(FIRERATE(W,M) NE 0), SUM((T,R),  
X(W,M,T,P,R)/FIRERATE(W,M))) +  
SUM((M,T,R), X(W,M,T,P,R) \* LOSSRATE(W,M,R)) -  
EXCESSW(W,P-1) ;

MUNPROD(M,P).. MPROD(M,P) =G=  
SUM((W,T,R), X(W,M,T,P,R)) -  
EXCESSM(M,P-1) ;

SETEXCESSW(W,P).. EXCESSW(W,P) =E=  
SUM(I\$(ORD(I) LE ORD(P)), WPROD(W,I)) -  
SUM(I\$(ORD(I) LE ORD(P)),  
SUM((M,T,R), X(W,M,T,I,R) \* LOSSRATE(W,M,R))) ;

SETEXCESSM(M,P).. EXCESSM(M,P) =E=  
SUM(I\$(ORD(I) LE ORD(P)),  
(MPROD(M,I) - SUM((W,T,R), X(W,M,T,I,R)))) ;

\*----- SOLVE MODEL USING RELAXED MIP -----\*

MODEL ARTYATTACK / ALL / ;

SOLVE ARTYATTACK USING RMIP MINIMIZING TOTCOST ;

\*---- GENERATE INTEGER SOLUTION BY ROUNDING RMIP SOLUTION -----\*

X.L(W,M,T,P,R) = CEIL(X.L(W,M,T,P,R)) ;  
WPROD.L(W,P) = CEIL(WPROD.L(W,P)) ;  
MPROD.L(M,P) = CEIL(MPROD.L(M,P)) ;

```

PARAMETER WEAPONS(*,*) ;
WEAPONS(W,'TOTAL #') = SUM(P,WPROD.L(W,P));

PARAMETER MUNITIONS(*,*) ;
MUNITIONS(M,'TOTAL #') = SUM(P,MPROD.L(M,P));

DISPLAY 'SOLUTION - PART I : WEAPON / MUNITION MIX:';
WPROD.L , WEAPONS, MPROD.L , MUNITIONS ;

DISPLAY 'SOLUTION - PART II : TARGET ALLOCATION ', X.L ;

*----- FIND TOTAL COST OF INTEGER SOLUTION -----*
SCALAR WHOLECOST ;
WHOLECOST = SUM((W,P), WPNCOSTS(W,'WPCOST') * WPROD.L(W,P)) +
SUM((W,P), WPNCOSTS(W,'WOCOSTP') * (SUM(I$(ORD(I) LE ORD(P)), WPROD.L(W,I))-SUM(I$(ORD(I) LE (ORD(P)-1)),SUM(M,T,R), X.L(W,M,T,I,R)) * LOSSRATE(W,M,R)))) + 
SUM((W,M,T,P,R), WPNCOSTS(W,'WOCOSTM') * X.L(W,M,T,P,R)) +
SUM((M,P), MUNCOSTS(M,'MPCOST') * MPROD.L(M,P)) +
SUM((M,P), MUNCOSTS(M,'MOCOST') * (SUM(I$(ORD(I) LE ORD(P)),MPROD.L(M,I)) - SUM(I$(ORD(I) LE (ORD(P)-1)), SUM((W,T,R), X.L(W,M,T,I,R)))))) ;

```

DISPLAY 'SOLUTION - PART III : TOTAL COST : ', TOTCOST.L , WHOLECOST ;

\* DETERMINE PERCENTAGE DIFFERENCE BETWEEN TWO SOLUTIONS:

```

SCALAR DELTA ;
DELTA = (WHOLECOST - TOTCOST.L) * 100 / TOTCOST.L ;

```

DISPLAY DELTA , ' % INCREASE USING ROUNDED UP SOLUTION ';

## APPENDIX B. AAM TEST CASE GAMS LISTING

1GAMS 2.19 IBM CMS 09/10/91 20:22:31 PAGE 1  
GENERAL ALGEBRAIC MODELING SYSTEM  
COMPILATION

1  
1GAMS 2.19 IBM CMS 09/10/91 20:22:31 PAGE 2  
----- ARTILLERY ATTACK MODEL -----  
-- COMBINED ARMS ARMY - OFFENSIVE SCENARIO --

4  
5  
6 \*\*----- GAMS AND DOLLAR CONTROL OPTIONS -----\*\*  
8  
9 OPTIONS SOLPRINT = OFF , LIMROW = 0, RESLIM = 10000  
10 OPTIONS OPTCR = 0.1 , LIMCOL = 0, ITERLIM = 100000  
11 OPTIONS SYSOUT = OFF ;  
12  
13  
14 \*\*----- DEFINITIONS AND INPUT DATA -----\*\*  
15  
16 SET W Weapon System / HIP Improved Howitzer  
17 MLRS Mult Launch Rocket  
18 Sys /  
19 M Munition Type /  
20 \* FOR HIP:  
21 DPICMH HIP Dual Pup Imp Conv  
22 HE High Explosive  
23 SADARMH HIP Sense\Destroy  
24 Armor  
25 TGP Term Guided Proj  
26 \* FOR MLRS:  
27 ATACMSI Army Tac  
28 Missile(DPICM)  
28 ATACMSII (Longer  
Range)  
29 DPICMM MLRS Dual Pup Imp  
Conv  
30 SADARMM MLRS Sense\Destroy  
31 Armor  
TGW Term Guided Warhead  
/

32  
 33  
 34 T Target Type /  
 35 ARTY Artillery Battery  
 36 MRC Motorized Rifle Company  
 37 TANK Tank Company  
 38 TOC Reg\Div Tac Ops Center  
 /  
 39  
 40  
 41 P Battle Phase / 1 Hour 1  
 42 2 Hour 2  
 43 3 Hour 3 /  
 44  
 45 R Target Range / 1 Tgt Between 0 - 30 KM Away  
 46 2 30 - 60  
 47 3 60 - 90  
 48 4 90 -120  
 /

1GAMS 2.19 IBM CMS 09/10/91 20:22:31 PAGE 3  
 ----- ARTILLERY ATTACK MODEL -----  
 -- COMBINED ARMS ARMY - OFFENSIVE SCENARIO --

49  
 50 WCOSTS Wpn Costs / WPCOST Wpn Production Cost  
 51 WOCOSTP O\S Cost per Battle  
 Phase  
 52 WOCOSTM O\S Cost per Msn  
 Fired /  
 53  
 54 MCOSTS Mun Costs / MPCOST Mun Production  
 Cost(Per Rd)  
 55 MOCOST O\S Cost per Battle  
 Phase/ ;  
 56  
 57  
 58 ALIAS (P,I) ;  
 59  
 60 PARAMETER DISTANCE(T) # Range Bands Tgt T Moves per  
 Phase  
 / ARTY 1  
 MRC 1  
 TANK 1  
 TOC 0 / ;  
 61  
 62  
 63  
 64  
 65  
 66  
 67  
 68 TABLE KILPERCENT(T,R) % Tgts Type T Required Killed  
 Range R  
 69  
 70 \* Range Range Range Range  
 71 1 2 3 4  
 72  
 73 ARTY 0.8 0.8 0.5 0.5



121  
 122  
 123  
 124 TABLE FIRERATE(W,M) Wpn\Mun Long-Term Sustained  
 125 \* Rate of Fire (Rds/Phase)  
 126  
 127 \* Weapon: Munition:  
 128 DPICMH SADARMH TGP HE  
 129 HIP 3 3 3 3  
 130  
 131 + DPICMM SADARMM TGW ATACMSI ATACMSII  
 132 MLRS 18 18 6 6 6  
 133  
 134  
 135  
 136 TABLE MAXRANGE(W,M) Max Range of Wpn\Mun Combination  
 137 \* (range band)  
 138  
 139 \* Weapon: Munition:  
 140 DPICMH SADARMH TGP HE  
 141 HIP 1 1 1 1  
 142  
 143 + DPICMM SADARMM TGW ATACMSI ATACMSII  
 144 MLRS 2 2 2 4 4  
 145  
 146  
 147  
 148 TABLE LOSSRATE(W,M,R) Wpn Rate of Loss to Enemy  
 Counterfire  
 1GAMS 2.19 IBM CMS 09/10/91 20:22:31 PAGE 5  
 ----- ARTILLERY ATTACK MODEL -----  
 - COMBINED ARMS ARMY - OFFENSIVE SCENARIO -  
  
 149 \* (% Wpns Disabled\Destr per Rd  
 Fired)  
 150  
 151 \* Munition: Range Range Range Range  
 152 1 2 3 4  
 153 HIP.DPICMH 0.04 0.00 0.00 0.00  
 154 HIP.HE 0.04 0.00 0.00 0.00  
 155 HIP.SADARMH 0.04 0.00 0.00 0.00  
 156 HIP.TGP 0.04 0.00 0.00 0.00  
 157 \* -----  
 158 MLRS.ATACMSI 0.10 0.05 0.01 0.01  
 159 MLRS.ATACMSII 0.10 0.05 0.01 0.01  
 160 MLRS.DPICMM 0.02 0.01 0.00 0.00  
 161 MLRS.SADARMM 0.02 0.01 0.00 0.00  
 162 MLRS.TGW 0.10 0.05 0.00 0.00  
 163  
 164  
 165  
 166 TABLE WPNCOSTS(W,WCOSTS) (Thousands of Dollars)  
 167  
 168 \* Weapon:

169	WPCOST	WOCOSTP	WOCOSTM
170	HIP	200	10
171			1
172	MLRS	2000	100
173			10
174			
175			

176 TABLE MUNCOSTS(M,MCOSTS) (Thousands of Dollars)

177	Munition:		
178 *	MPCOST	MOCOST	
179	ATACMSI	200.0	0.5
180	ATACMSII	400.0	0.5
181	DPICMH	0.8	0.1
182	DPICMM	5.0	0.4
183	HE	0.3	0.1
184	SADARMH	10.0	0.2
185	SADARMM	20.0	0.4
186	TGP	10.0	0.2
187	TGW	100.0	0.4
188			;
189			
190			
191			

192 \*\*----- ARTILLERY ATTACK MODEL -----\*\*

193			
194			
195	POSITIVE		
196	VARIABLES		
197	EXCESSM(M,P)	# Mun M Remaining End Phase P	
198			
199	EXCESSW(W,P)	# Wpn W Remaining End Phase P	
200			
201	TGTS(T,P,R)	Total Tgts T \ Phase P \ Range R	
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----- ARTILLERY ATTACK MODEL -----

-- COMBINED ARMS ARMY - OFFENSIVE SCENARIO -

202 *	on Battlefield (Before Losses)	
203	INTEGER	
204	VARIABLES	
205	MPROD(M,P)	# Mun M Produced\Resupplied for Phase P
206		
207	WPROD(W,P)	# Wpn W Produced\Resupplied for Phase P
208		
209	X(W,M,T,P,R)	# Mans Fired by All Wpn W\Mun M Combo ;
210 *	at Tgt T \ Phase P \ Range R	
211		
212 *	SET BOUNDARIES	
213	MPROD.LO(M,P) = 0	;
214	MPROD.UP(M,P) = 400	;

```

215
216      WPROD.LO(W,P) = 0      ;
217      WPROD.UP(W,P) = 50      ;
218
219      X.LO(W,M,T,P,R) = 0    ;
220      X.UP(W,M,T,P,R) = 400  ;
221
222 *      Set Model Not to Attack Targets Out of Range:
223      X.FX(W,M,T,P,R)$ORD(R) GT MAXRANGE(W,M)) = 0
224 *      Set Model Not to Use Incompatible Wpn\Mun Combos:
225      X.FX(W,M,T,P,R)$EFFECTS(W,M,T) EQ 0) = 0
226
227 VARIABLE    TOTCOST      Total Cost of Weapons and
228 *                  Munitions ;
229
230 *-----
231
232 EQUATIONS    OBJ      Calculate Total Cost of Wpns and
233                  Muns
234      NUMTGT(T,P,R) Determine # Tgts T at Range R
235                  Phase P
236      MINKILLS(T,P,R) Meet Kill Crit Tgt T Phase P
237                  Range R
238      MAXKILLS(T,P,R) Limit Engagements to Existing Tgts
239
240      WPNPROM(W,P)   Determine Wpn Prod\Resupply
241                  Requirements
242      MUNPROD(M,P)   Determine Mun Prod\Resupply
243                  Requirements
244      SETEXCESSW(W,P) Determine # Wpn W Remaining End
245                  Phase P
1GAMS 2.19 IBM CMS      09/10/91 20:22:31 PAGE    7
246      _____ ARTILLERY ATTACK MODEL _____
247      - COMBINED ARMS ARMY - OFFENSIVE SCENARIO -
248
249
250
251 *-----
252
253 * Minimize Total Cost :
254

```

```

255   OBJ..  TOTCOST =E= SUM((W,P), WPNCOSTS(W,'WPCOST') *
256   WPROD(W,P)) +
257   SUM((W,P), WPNCOSTS(W,'WOCOSTP') *
258   (SUM(I$(ORD(I) LE ORD(P)), WPROD(W,I))-*
259   SUM(I$(ORD(I) LE (ORD(P)-1)),SUM((M,T,R),
260   X(W,M,T,I,R) * LOSSRATE(W,M,R)))))) +
261   SUM((W,M,T,P,R), WPNCOSTS(W,'WOCOSTM') *
262   X(W,M,T,P,R)) +
263   SUM((M,P), MUNCOSTS(M,'MPCOST') *
264   MPROD(M,P)) +
265   SUM((M,P), MUNCOSTS(M,'MOCOST') *
266   (SUM(I$(ORD(I) LE ORD(P)),MPROD(M,I)) -
267   SUM(I$(ORD(I) LE (ORD(P)-1)), SUM((W,T,R,
268   X(W,M,T,I,R)))))) +
269   ;
270   ;
271   ;
272   ;
273 * Subject To :
274   ;
275   ;
276   NUMTGTS(T,P,R)..  TGTS(T,P,R) =E= TGTS(T,P-1,R +
277   DISTANCE(T)) -
278   SUM((W,M), X(W,M,T,P-1,R + DISTANCE(T)
279   ) * *
280   ) +
281   EFFECTS(W,M,T)) + NEWTGTS(T,P,R)
282   ;
283   MINKILLS(T,P,R)..  SUM((W,M), X(W,M,T,P,R) *
284   EFFECTS(W,M,T)) =G=
285   TGTS(T,P,R) * KILPERCENT(T,R)
286   ;
287   MAXKILLS(T,P,R)..  SUM((W,M), X(W,M,T,P,R) * EFFECTS(W,M,T)
288   ) =L=
289   TGTS(T,P,R)
290   ;
291   1GAMS 2.19 IBM CMS          09/10/91 20:22:31 PAGE     8
292   ----- ARTILLERY ATTACK MODEL -----
293   -- COMBINED ARMS ARMY - OFFENSIVE SCENARIO --
294   ;
295   WPNPROD(W,P)..  WPROD(W,P) =G=
296   SUM(M$(FIRERATE(W,M) NE 0), SUM((T,R),
297   X(W,M,T,P,R)/FIRERATE(W,M))) +
298   SUM((M,T,R), X(W,M,T,P,R) *
299   LOSSRATE(W,M,R))-

```

```

294      EXCESSW(W,P-1)
295      ;
296
297      MUNPROD(M,P)..  MPROD(M,P) =G=
298      SUM((W,T,R), X(W,M,T,P,R)) -
299      EXCESSM(M,P-1)
300      ;
301
302      SETEXCESSW(W,P)..  EXCESSW(W,P) =E=
303      SUM(I$(ORD(I) LE ORD(P)), WPROD(W,I))
304
305      SUM(I$(ORD(I) LE ORD(P)),
306      SUM((M,T,R), X(W,M,T,I,R)*
307      LOSSRATE(W,M,R))) ;
308
309      SETEXCESSM(M,P)..  EXCESSM(M,P) =E=
310      SUM(I$(ORD(I) LE ORD(P)),
311      (MPROD(M,I) - SUM((W,T,R),
312      X(W,M,T,I,R)))) ;
313
314 *----- SOLVE MODEL USING RELAXED MIP
315
316
317 MODEL ARTYATTACK / ALL / ;
318
319 SOLVE ARTYATTACK USING RMIP MINIMIZING TOTCOST ;
320
321
322 *--- GENERATE INTEGER SOLUTION BY ROUNDING RMIP SOLUTION
323
324 X.L(W,M,T,P,R) = CEIL(X.L(W,M,T,P,R)) ;
325 WPROD.L(W,P) = CEIL(WPROD.L(W,P)) ;
326 MPROD.L(M,P) = CEIL(MPROD.L(M,P)) ;
327
328
329 PARAMETER WEAPONS(*,*) ;
330 WEAPONS(W,'TOTAL #') = SUM(P,WPROD.L(W,P));
331
332
333 PARAMETER MUNITIONS(*,*) ;
334 MUNITIONS(M,'TOTAL #') = SUM(P,MPROD.L(M,P));
335
1GAMS 2.19 IBM CMS          09/10/91 20:22:31 PAGE  9
----- ARTILLERY ATTACK MODEL -----
- COMBINED ARMS ARMY - OFFENSIVE SCENARIO -

```

336

```

337  DISPLAY 'SOLUTION - PART I : WEAPON / MUNITION MIX:',  

338      WPROD.L , WEAPONS, MPROD.L , MUNITIONS ;  

339  

340  

341  DISPLAY 'SOLUTION - PART II : TARGET ALLOCATION ' , X.L ;  

342  

343  

344 *----- FIND TOTAL COST OF INTEGER SOLUTION  

-----*  

345  

346  SCALAR WHOLECOST ;  

347  

348  WHOLECOST = SUM((W,P), WPNCOSTS(W,'WPCOST') * WPROD.L(W,P))  

+  

349          SUM((W,P), WPNCOSTS(W,'WOCOSTP') *  

350          (SUM(I$(ORD(I) LE ORD(P)), WPROD.L(W,I))-  

351          SUM(I$(ORD(I) LE (ORD(P)-1)),SUM((M,T,R),  

352          X.L(W,M,T,I,R) * LOSSRATE(W,M,R)))) +  

353  

354          SUM((W,M,T,P,R), WPNCOSTS(W,'WOCOSTM') *  

355          X.L(W,M,T,P,R)) +  

356  

357          SUM((M,P), MUNCOSTS(M,'MPCOST') *  

358          MPROD.L(M,P)) +  

359  

360          SUM((M,P), MUNCOSTS(M,'MOCOST') *  

361          (SUM(I$(ORD(I) LE ORD(P)),MPROD.L(M,I)) -  

362          SUM(I$(ORD(I) LE (ORD(P)-1)), SUM((W,T,R)  

363          X.L(W,M,T,I,R))))))  

;  

364  

365  

366  DISPLAY 'SOLUTION - PART III : TOTAL COST : ', TOTCOST.L ,  

      WHOLECOST ;  

367  

368  

369 * DETERMINE PERCENTAGE DIFFERENCE BETWEEN TWO SOLUTIONS:  

370  SCALAR DELTA ;  

371      DELTA = (WHOLECOST - TOTCOST.L) * 100 / TOTCOST.L ;  

372  

373  DISPLAY DELTA , '% INCREASE USING ROUNDED UP SOLUTION ' ;  

374

```

```

COMPILE TIME      -      0.310 SECONDS
1GAMS 2.19 IBM CMS      09/10/91 20:22:31 PAGE      10
----- ARTILLERY ATTACK MODEL -----
MODEL STATISTICS  SOLVE ARTYATTACK USING RMIP FROM LINE 319

```

MODEL STATISTICS

BLOCKS OF EQUATIONS 8 SINGLE EQUATIONS 211  
BLOCKS OF VARIABLES 7 SINGLE VARIABLES 979  
NON ZERO ELEMENTS 5744 DISCRETE VARIABLES 249

GENERATION TIME = 2.290 SECONDS

EXECUTION TIME = 2.470 SECONDS  
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----- ARTILLERY ATTACK MODEL -----  
SOLUTION REPORT SOLVE ARTYATTACK USING RMIP FROM LINE 319

#### S O L V E     S U M M A R Y

MODEL ARTYATTACK OBJECTIVE TOTCOST  
TYPE RMIP DIRECTION MINIMIZE  
SOLVER ZOOM FROM LINE 319

\*\*\*\* SOLVER STATUS 1 NORMAL COMPLETION  
\*\*\*\* MODEL STATUS 1 OPTIMAL  
\*\*\*\* OBJECTIVE VALUE 130805.9741

RESOURCE USAGE, LIMIT 1.346 10000.000  
ITERATION COUNT, LIMIT 218 100000

Z O O M / X M P --- Version 2.1 Jun 1988

Courtesy of Dr Roy E. Marsten,  
Department of Management Information Systems,  
University of Arizona,  
Tucson Arizona 85721, U.S.A.

#### PROBLEM SPECIFICATIONS

BEGIN  
\*  
\* MAX SAVE 30 number of hot LP bases saved during B&B  
\* ORDER 1 control order of branching 1, 2, or 3  
\* number of attractive nonbasic var.  
\* saved during major iter.  
MULTIPLE 30 relative gap between opt int. ans and LP ans.  
\*GAP 0.5  
\*INCUMBENT = 0.215495  
\* how often to revert basis  
INVERT = 10 control amount of printing  
PRINT LP1 1  
PRINT BRANCH 0

END

Work space needed (estimate) -- 31855 words.  
Work space available -- 31855 words.  
Maximum obtainable -- 291069 words.

The LU factors occupied 747 slots (estimate 7464).

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----- ARTILLERY ATTACK MODEL -----  
SOLUTION REPORT SOLVE ARTYATTACK USING RMIP FROM LINE 319

\*\*\*\* REPORT SUMMARY : 0 NONOPT  
0 INFEASIBLE  
0 UNBOUNDED

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----- ARTILLERY ATTACK MODEL -----  
E X E C U T I N G

--- 337 SOLUTION - PART I : WEAPON / MUNITION MIX:

--- 337 VARIABLE WPROD.L # WPN W PRODUCED\RESUPPLIED FOR  
PHASE P

1

HIP 23.000  
MLRS 38.000

--- 337 PARAMETER WEAPONS

TOTAL #

HIP 23.000  
MLRS 38.000

--- 337 VARIABLE MPROD.L # MUN M PRODUCED\RESUPPLIED FOR  
PHASE P

1 2 3

DPICMH	54.000	48.000
TGP	60.000	
ATACMSI	68.000	18.000
DPICMM		1.000
TGW	231.000	33.000
	106.000	29.000

— 337 PARAMETER MUNITIONS

TOTAL #

DPICMH	102.000
TGP	60.000
ATACMSI	88.000
DPICMM	264.000
TGW	171.000

— 341 SOLUTION - PART II : TARGET ALLOCATION  
1GAMS 2.19 IBM CMS 09/10/91 20:22:43 PAGE 14  
— ARTILLERY ATTACK MODEL —————  
EXECUTING

— 341 VARIABLE X.L # MSNS FIRED BY ALL WPN W\MUN M  
COMBO

INDEX 1 = HIP INDEX 2 = DPICMH

1

MRC .2	54.000
MRC .3	48.000

INDEX 1 = HIP INDEX 2 = TGP

1

MRC .1	60.000
--------	--------

INDEX 1 = MLRS INDEX 2 = ATACMSI

1	3	4
---	---	---

ARTY.1	6.000	15.000
ARTY.2	8.000	
MRC .1	1.000	2.000
MRC .2	2.000	
TANK.1	25.000	9.000 3.000
TANK.2	9.000	
TOC .1	5.000	5.000
TOC .2	1.000	1.000
TOC .3	1.000	1.000

INDEX 1 = MLRS INDEX 2 = DPICMM

1	2
---	---

MRC .2	222.000
MRC .3	1.000 30.000
TOC .2	10.000
TOC .3	2.000

INDEX 1 = MLRS INDEX 2 = TGW

	1	2
ARTY.1	8.000	59.000
ARTY.2	12.000	4.000
ARTY.3	1.000	6.000
MRC .1		32.000
MRC .2	2.000	4.000
TANK.2		15.000
TANK.3	9.000	15.000
TOC .1		8.000

--- 366 SOLUTION - PART III : TOTAL COST :  
1GAMS 2.19 IBM CMS 09/10/91 20:22:43 PAGE 15  
----- ARTILLERY ATTACK MODEL -----  
EXECUTING

--- 366 VARIABLE TOTCOST.L = 130805.974 TOTAL COST  
OF WEAPONS  
AND MUNITIONS  
PARAMETER WHOLECOST = 132586.600

--- 373 PARAMETER DELTA  
= 1.361 % INCREASE USING ROUNDED UP SOLUTION

\*\*\*\* FILE SUMMARY FOR USER 8876P

INPUT AAM5 GAMS A  
OUTPUT AAM5 LISTING A

EXECUTION TIME = 0.460 SECONDS

## LIST OF REFERENCES

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2. U.S. Army Field Artillery School, Directorate of Combat Developments, *Legal Mix VII Study - Field Artillery Operations in Support of AirLand Battle Future*, p. 5-2, March 1991.
3. The discussion of future artillery systems is based upon Anderson, E.G., "Reshaping the Field Artillery," *Field Artillery Journal*, June 1991.
4. The Artillery Attack Model is based upon Wroth, MAJ M., *The Long Range Fires Attack Model - Proof of Principle, Prototype Model*, U.S. Army Field Artillery School, Fort Sill, Oklahoma, December 1990. MAJ Wroth's model is a small-scale prototype intended to demonstrate that Linear Programming (LP) has the potential to be applied to the weapons/munitions mix problem. This study is being conducted to develop a full-scale working LP model for DCD, USAFAS to use to solve the weapons/munitions composition and allocation problem.
5. Heterogeneous Aggregation and aspects of aggregated modeling are discussed by Hartman, J.K., *Aggregated Combat Modeling*, ch. 2, Naval Postgraduate School, 1985.
6. Brooke, A., Kendrick, D., and Meeraus, A., *GAMS - A User's Guide*, The Scientific Press, 1988.

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